

## Review Article

# A Systematic Review of Research on Outrigger Canoe Paddling and Racing

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## Abstract

**Purpose:** Research on outrigger canoe paddling performance is in its infancy and only began in the late 1990s. This paper systematically identified and reviewed previously published peer-reviewed articles and theses, and summarized the findings with the aim of defining the current state of knowledge on the sport.

**Method:** Using a systematic review, searches were conducted on PubMed MEDLINE, Academic Search Premier, Cochrane Library databases and Google Scholar for articles published up to June 2014. A standard systematic review process was applied to sift abstracts and full texts to obtain and extract data on study characteristics, measurements and recommendations.

**Results:** Twenty-seven articles by eleven lead authors were identified. There was fairly close consensus on anthropometrics, peak physiological measurements, stroke variables, injury prevalence and paddle design. Most non-injury studies relied on small data sets and had limited statistical power.

**Conclusions:** The results identified in this review provide a starting point for more systematic research that identifies and quantifies performance predictors in outrigger canoe racing.

## Keywords

- Biomechanics
- Peak performance
- Sports injury
- OC1
- OC6

## INTRODUCTION

From an international perspective, Polynesian outrigger canoe racing is a relatively new sport compared with other paddle sports that have become Olympic events, such as canoeing and kayaking. Performance is more highly tuned in highly competitive Olympic sports, which receive more attention from sports science researchers [1-3]. A Google Scholar search, minus citations and patents, indicated relative research activity in various paddling sports: “kayak” OR “kayaking” 6250 hits; “dragon boat” 4730 hits; “outrigger canoe” OR “outrigger canoeing” OR “outrigger paddle” OR “outrigger paddlers” OR “outrigger paddling” 1920 hits. “Canoeing” is an indiscriminate term and resulted in 34,000 hits. Major areas of research have included health and wellbeing, paddler physiology, biomechanical characteristics of elite paddlers, and technical studies on paddles and canoe performance.

In Hawai’i, competitive outrigger clubs typically require paddlers to train three times a week with races or longer training sessions scheduled on Sundays. Cross-training and strength-training are employed by some paddlers seeking to maintain fitness and physique or improve performance. In Australia, paddlers also train thrice weekly with five additional cross-

trainings [4]. This level of commitment requires coaches to be conscientious in providing athletes with training regimes and advice that enables them to achieve optimum performance.

Outrigger coaches primarily gain their information from experience, observing successful crews and word-of-mouth from other coaches or crew analysts. Those inclined to review published information are limited to texts and research articles from kayaking or dragon boating [5-8]. Drawing from experience or research on other sports may not, however, result in practices that elicit optimal performance given that outrigger canoeing is a different sport and all the factors that contribute to optimum performance in outrigger canoeing have not been identified or evaluated. While the top clubs in Hawaii anecdotally show a similar style, indicating convergence rather than diversity, the lack of empirical evidence-based data may result in the perpetuation of practices showcased by successful clubs and crews that have no effect on performance or which are detrimental to performance. What works for one six-man crew will not necessarily work for another due to differences in body composition, aerobic fitness, strength, experience, paddle selection, paddling style, stroke rate, crew placement and steersman capability. Contributions from

research help to provide evidence to support or refute particular trainings and may assist with athlete selection, performance monitoring, technique modification and race strategy.

While there are similarities between paddling sports, it is important to build up a body of knowledge and an empirical evidence-base for each sport to ensure that coaches make the most appropriate training and racing decisions. This systematic review focused on research conducted specifically on performance-related aspects of outrigger canoeing and paddling with the aim of defining the current state of knowledge on the sport.

## METHODS

This systematic review was guided by the PRISMA Statement and its 27-item checklist. The aim of the PRISMA Statement is to assist authors in the reporting of systematic reviews [9]. In June 2014, searches were conducted in PubMed MEDLINE, Academic Search Premier, Cochrane Library databases and Google Scholar. The search terms used were “outrigger canoe” OR “outrigger canoeing” OR “outrigger paddle” OR “outrigger paddlers” OR “outrigger paddling” OR “outrigger racing.” Eligibility criteria were created to independently screen the titles and descriptors/abstracts recovered during the literature search. After non-relevant articles were removed, the remaining articles were compiled and the full text of each was read to assess eligibility for inclusion.

Publications were eligible for inclusion in this review if they were published in English in a peer-reviewed journal any year up to June 2014. Theses, dissertations and non-fictional books were also included. The publication had to focus on performance factors relating to outrigger canoeing. The search was not restricted by country. Source tracking was employed to identify further articles of relevance to the topic.

## RESULTS

Of the 1970 articles identified through four databases, 19 non-English articles and 21 duplicate articles were removed in addition to 1903 non-relevant articles based on titles and descriptors or abstracts (Figure 1). Some texts that included much experiential information were excluded since the data was not collected using scientific methodology [6-8]. The 27 remaining articles, published between 1982 and 2013, were the focus of this systematic literature review (Figure 2).

Table (1) presents the anthropometric data found in 20 of the reviewed articles. Participant numbers were low in all but the study by Bell et al., [10] and tended to focus on either men or women. The average age of paddler participants was 31 yrs, compared to female paddlers, anthropometric averages for males were: weight +10.4 kg; arm span +10.8 cm; height +8.9 cm; sitting height +3.1 cm; humeral width +0.8 cm; and body fat -15%.

Gas analysis aerobic systems use indirect calorimetry to measure the rate of oxygen consumption ( $\text{VO}_2$ ), respiratory rate (RR), respiratory exchange ratio (RER) and ventilation rate (VE). These physiological measures in addition to oxygen saturation ( $\text{SaO}_2$ ), peak heart rate (HR) and peak blood lactate provide quantitative indicators of the physiological demand of outrigger paddling and the physiological capacity of the competitors.

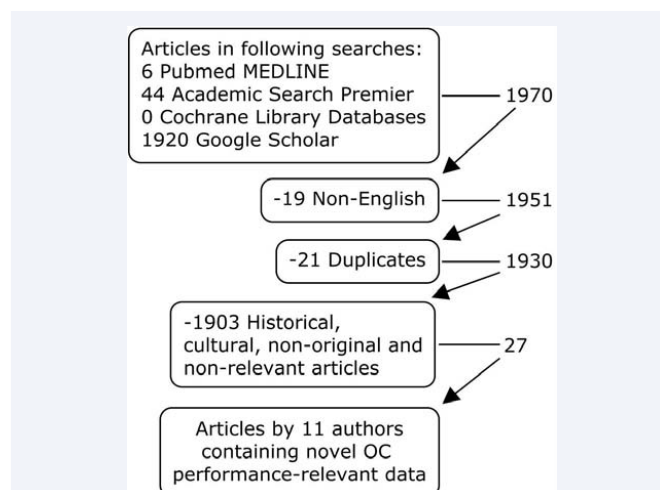


Figure 1 Evolution of articles included in this review.

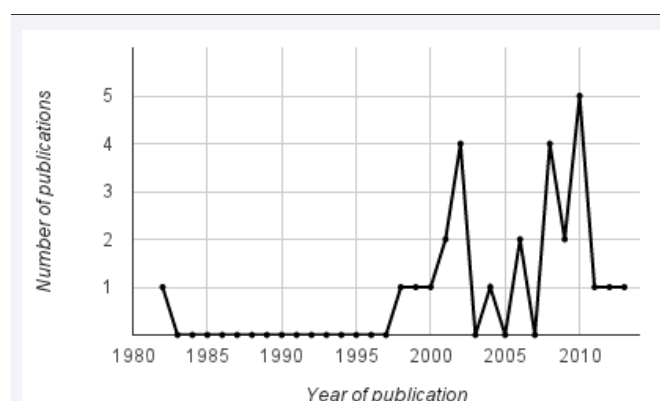


Figure 2 Number of evidence-based publications on outrigger canoeing from 1982 to June 2014.

Of these physiological variables, peak  $\text{VO}_2$  has been reported to correlate with time trial performance and therefore may contribute to the prediction of outrigger paddling performance and crew selection [11,12]. Table (2) depicts papers and theses by four leading authors who have investigated these variables in a total of 72 outrigger paddlers.

Some of these researchers and one other, all based in Australia, have also investigated the relationship between various aspects of stroke: force, rate per minute and length. A repetitive cyclic movement is used by paddlers, who adopt a style based on their range of movement, required stroke rate and paddle design [6,8]. Depending on environmental circumstances, fitness, race distance and the predominant paddling style, stroke rates vary from 42 to 70 strokes per minute [5,6,8]. To date, it is not known whether these variations in paddling style affect performance. Table 3 shows findings on biomechanical stroke characteristics in outrigger paddling (Table 3).

Two studies have investigated the offset angle of the blade in comparison to a blade that is in line with the paddle shaft (Table 4). Both studies found that an offset angle improved performance and vessel speed.

**Table 1:** Anthropometric characteristics of outrigger paddlers as means and (standard deviations).

Refs	Origin Ethnicity	Partici-pants	Age Years	Weight kg	Height cm	Sitting height cm	Arm span cm	Humeral width cm	Body fat %
Males									
11	Australia	12 ♂	31.0 (8.3)	80.5 (10.5)	--	--	--	--	--
12	Australia	13 ♂	26.9 (8.9)	79.9 (13.4)	175.0 (5.4)	100.4 (2.2)	178.1 (7.4)	7.2 (0.2)	--
13,14	Canada	22 ♂	35.6 (5.7)	84.4 (9.2)	179.2 (3.8)	91.8 (2.1)	183.8 (6.4)	--	--
15	Australia	12 ♂	31.3 (8.3)	80.5	181.3	91.9	184.3	--	14.9 (2.4)
♂ Means		14.7	31.2	81.3	178.5	94.7	182.1	7.2	14.9
Females									
12	Australia	8 ♀	25.6 (6.1)	70.3 (8.0)	168.1 (5.3)	97.0 (2.5)	170.0 (4.9)	6.5 (0.4)	--
7,16-26	Australia	10-17 ♀	30 (8) - 34.2 (8.7)	69 (9) - 76 (16)	168 (6) - 170 (8)	89.7 (3.4)	168.8 (7.3)	6.2 (0.4)	25 (7) - 33 (7)
27	N/A	9 ♀	35.0 (8.0)	71.0 (8.0)	173.0 (7.0)	88.0 (2.0)	175.0 (8.0)	--	
♀ Means		9.0-11.3	30.2-31.6	70.1-72.4	169.7-170.4	91.6	171.3	6.4	25-33
10	NZ 51% Maori	145 ♂ 95 ♀	33.5 (11.8)	83.6 (9.0)	177.4 (6.2)	--	--	--	--

**Table 2:** Peak physiological characteristics of outrigger paddlers as means and (standard deviations).

Refs	HR b/min	VO <sub>2</sub> L/min	RR br/min	RER	VE L/min	SaO <sub>2</sub> %	Post lactate mmol/L
Males							
12	188 (8.0)	3.0 (0.4)	--	--	--	--	8.7 (1.8)
13,14	175.7 (9.4)	3.88 (0.5)	62.3 (8.1)	--	151.9 (17.3)	92.7 (2.6)	--
15	183.1 (11.4)	--	--	--	--	--	11.1 (2.0)
♂ Means	182.3	3.44	62.3	--	151.9	92.7	9.9
Females							
12	185 (8.3)	2.3 (0.5)	--	--	--	--	8.6 (1.5)
16,19,20,22-24	174 (10) - 177 (11)	3.00 (0.2) - 3.23 (0.48)	57 (9) - 59 (9)	1.05 (0.09) - 1.10 (0.09)	104.4 (12.7) - 117.8 (14.6)	--	6.3 (1.5) - 13.5 (2.2)
♀ Means	179.5-181	2.65-2.77	57.0-59.0	1.05-1.10	104.0-117.8	--	7.45-11.05

**Table 3:** Biomechanical stroke characteristics of outrigger paddling.

Refs	Findings
11	SR between 50-90 progressively and positively correlated with rate of SF development and SF SR between 80-90 resulted in peak SF SR negatively associated with SL
12	SF load cell Male dominant - 382 (65.8) N; non-dominant - 369 (69.0) N Female dominant - 252 (62.7) N; non-dominant - 257 (59.6) N
7	In Australia, 2-9% coaches promote a slow SR of around 45; 81% use 55-65; and 10-17% use 70+.
26	Compared stroke kinematics at SR 54, 61 and 70 SR negatively associated with SL SR not correlated with time spent in propulsive and recovery phases SR not correlated with trunk 'twist'

22	Compared physiology at SR 54, 61 and 70 Post lactate significantly higher at SR 70 Rating of perceived exertion (RPE) significantly higher at SR 70
15	Peak force 787.6 (243.6) N at SR 90 Highest mean force 243.9 (18.6) N at SR 80 Mean rate of SF development 1381 (330) N/sec SR correlated with rate of SF development SR negatively correlated with SL SR negatively correlated with trunk flexion
*SF - stroke force; SR - stroke rate (strokes per minute); SL - stroke length	

**Table 4:** Laboratory-based outrigger paddle studies.

Refs	Findings
28,29	Created a model of the paddle stroke and experimented with different blade offset angles - found greatest boat velocity from 10 to 30 degrees
30	Biomechanical analysis of straight and 15 degree offset blades Straight blade significantly lower mean canoe velocity than angled blade (290 cm/sec vs. 306 cm/sec)

**Table 5:** Musculoskeletal injury and pain studies and preventative training studies on outrigger paddlers (OR = odds ratio).

Refs	Canoe and Racing Effects	Musculoskeletal Injuries	Training Perceptions and Modalities
10	Risk of injury OC1 OR 0.46 OC6 OR 1.80 OC12 OR 2.85 Sprint OR 0.81 Distance OR 1.44	42% of 240 injured: Shoulder 35% Spine 27% Arm/wrist 16% No link with sex or age	--
31	Injury prevalence Sprint 13.6% Distance 51.2%	62% of 278 injured: Shoulder 40% Spine 35% Arm/wrist 24.2% No incidence data No link w/ sex, age, OC6 seat	--
33	--	85% of 21 injured - <u>Injuries</u> : Shoulder 41% Low back 32% Elbow 5% <u>Perceptions of cause</u> : Poor flexibility 42% Weakness/imbalance 42% Insufficient warm-up 16%	Effectiveness at preventing injury: Endurance training 68% Strength training 67% Technique training 32%
32	--	--	Power and endurance training for sprints. Endurance training for distance. Resistance training prevents injury. Monitor for overtraining
4	--	47% males & 50% females of 101 injured: Shoulder 28% Low back 25% No incidence data	Ergometer use 55% Sports scientist use 52%
34	--	Pain perception not associated with gender or self-efficacy. Catastrophizing and distraction most significant coping strategies.	--

Six articles were identified that focused on musculoskeletal injury, pain and training specifically designed to reduce the likelihood of injury (Table 5).

## DISCUSSION

Humphries et al., [12] concluded that paddlers exhibit above-average values for height and mass, aerobic power and muscular strength characteristics. The isokinetic strength tests

showed evidence of an imbalance between the dominant and non-dominant sides of the body for flexion and extension of the shoulder joint. It was thus stated that training should focus on correcting these muscular strength imbalances. It was assumed that imbalance was due to dominance rather than OC1 paddling habits which can result in a paddler favoring the left side. Humphries et al., [12] also reported a statistical relationship between 250 m OC1 sprint performance and a variety of anthropometric and physiological measures. Specifically, faster

time trial performance was associated with greater values for height, sitting height, arm span and bone width, as well as  $\text{VO}_2$ , strength and peak paddle force.

LaBreche [13] and LaBreche & McKenzie [14] concluded that leg drive does not affect the metabolic demand (energy cost) of paddling.

Kerr et al [15,16-20] found that younger smaller leaner more aerobically fit females were slower than older, heavier but more powerful paddlers in sprint races. They thus concluded that sprint times rely more on power than aerobic fitness. They found that the ergometer-based 1000m time trial was suitable for physiological evaluations and thus assessing paddlers for crew selection. They concluded that enhanced performance in 1000m sprints is achieved through greater power production and maintenance, muscular stature and to a lesser extent, aerobic capacity.

In their research on female paddlers, Sealey et al., (nee Kerr) [7,21-26] recommended that coaches select crew members based on three selection criteria: 1) able to generate and maintain high power output throughout a 1000 m time trial, 2) have a mesomorphic body stature, and 3) have a high peak  $\text{VO}_2$ . Aerobic capacity was considered of secondary importance. They found that a 1000 m ergometer time trial was suitable for assessing performance and aerobic capacity simultaneously. To optimize performance, they recommended that coaches adopt 1) a fast start and fast finish race pacing strategy in 1000 m outrigger sprint races, and 2) a paddling rate of 55 strokes per minute. This stroke rate was found to be less physiologically demanding than 70 strokes per minute, but no less fast because it involved less compromise of technique consistency. Because of the small sample size, it is still unconfirmed as to whether this stroke recommendation can be applied broadly. It is perhaps not even possible to apply laboratory-based and flat-water stroke results to ocean paddling where the changing water requires constant changes in stroke rate and style.

Dascombe et al., [11] examined the relationship between increasing stroke rates and force production. They found a strong positive association between 50 and 90 strokes and concluded that a stroke rate of 80-90 provided the greatest force production for sprint races. This data was collected during tethered OC1 paddling therefore while the results are more applied than the ergometer research carried out by Sealey and colleagues, it may still not completely capture the sometimes unpredictable (due to weather conditions) ocean paddling performance.

Caplan [27-29] and Nolan & Bates [30] investigated the effect of offsetting the angle of an outrigger paddle blade and found that an offset of between 10 and 30 degrees produced significantly more power than a straight paddle. Power was expressed in terms of increased vessel velocity. Outrigger paddle blades are tear-shaped and while it was common that Hawaiian blades were larger than Tahitian blades [6,8], this is no longer the case.

Haley and Nichols [31] surveyed paddlers in O'ahu Hawai'i and found that musculoskeletal injuries were common in outrigger canoe paddlers with most injuries being mild in severity and short in duration. Injuries were not associated with sex or age. They observed that paddlers participating in both the

long and short distance seasons sustained more injuries than those participating only in sprint races.

Bell et al., [10] concluded that competitive outrigger paddling is relatively less injurious than other sports with an overall risk of 1.82 injuries per 1000 hours of exposure. The majority of injuries were not serious although a significant portion were moderate to severe and potentially received no treatment. They found that the majority of injuries were sprains and shoulder strains followed by spine and arm/wrist injuries. These injury sites were dissimilar to those in rowers. Those that became injured were more likely to participate in long distance events and paddle in OC6 or OC12 canoes. In addition to paddling, lifting and moving the canoes was identified as an injury mechanism.

Stanton [4,15,32-34] found that over two thirds of paddlers use strength training and over half use ergometers and sports scientists to improve performance and reduce the likelihood of injury. Similar to the previous injury studies, half of paddlers reported injuries mostly to the shoulder and lower back. These were largely attributed to poor flexibility and muscular imbalances.

Findings from the limited articles published to date indicate that a combination of anthropometric, physiological and biomechanical technique factors influence performance. A larger stature, high power production and high  $\text{VO}_2$  appear to predict successful performance; and a fast stroke rate as achieved by a concurrent reduction in stroke length appears to produce greater force but may be more physiologically demanding. An angled paddle appears beneficial, and evidence of muscle imbalances may contribute to injuries, which most often occur at the shoulder.

## Practical applications

Limitations of this study included only reviewing articles published in English. Limitations in the studies reviewed included limited methodology with all studies being cross-sectional and many studies had too few participants with low statistical power to be able to draw generalizable conclusions. When information on years of experience, level of fitness, category of racing, type of races and type of training were supplied, there were insufficient numbers to permit the provision of sufficient statistical analysis. Participants were thus pooled for analysis leaving very little in the way of specific evidence-based empirical information. The papers on training highlighted useful methods, but the short term data collection did not capture long term effects of the trainings. The injury studies were primarily based on self-reported data involved evaluation that was often dependent on questionnaires that had not been validated. The heterogeneous nature of the studies, including the instrumentation and metrics they employed, rendered it difficult to compare results and impossible to conduct a meta-analysis, with a majority of studies focusing on sprint performance and the use of ergometers instead of on-water performance. Publication bias was not considered important since most studies were descriptive and not testing a particular intervention for positive impact.

Research on outrigger canoeing has been almost non-existent and sporadic as it has been underfunded and has relied heavily on graduate student and Australian researchers. The empirical evidence base for outrigger canoe paddling is limited with half



of the non-injury studies originating from one geographic region and based on ergometer performance. There is a need for a more systematic approach to outrigger research. Larger studies are required with sufficient paddlers in all age, gender and canoe type competition categories, to enable meaningful statistical analysis and interpretation. Investigations on elite, competitive and novice paddlers are required to determine current best practice. There is a need for academic researchers to partner with outrigger industries, associations, clubs and athletes in the conduct of meaningful studies that provide an evidence-base to support enhanced performance and the advancement of the sport of outrigger canoe racing. The results identified in this review provide a starting point for future research that identifies and quantifies performance predictors in outrigger canoe racing.

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